Water and the Electrical Conductivity of the Moon

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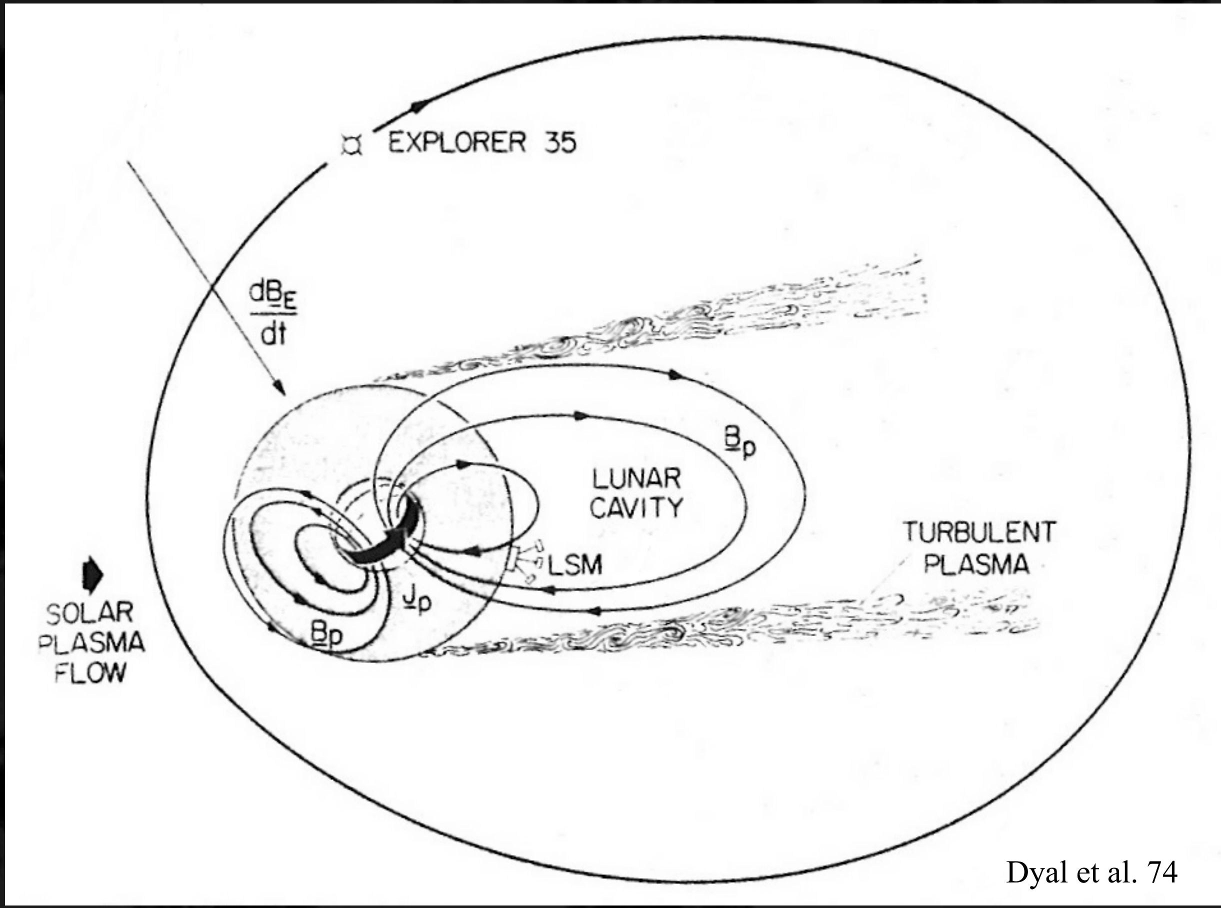
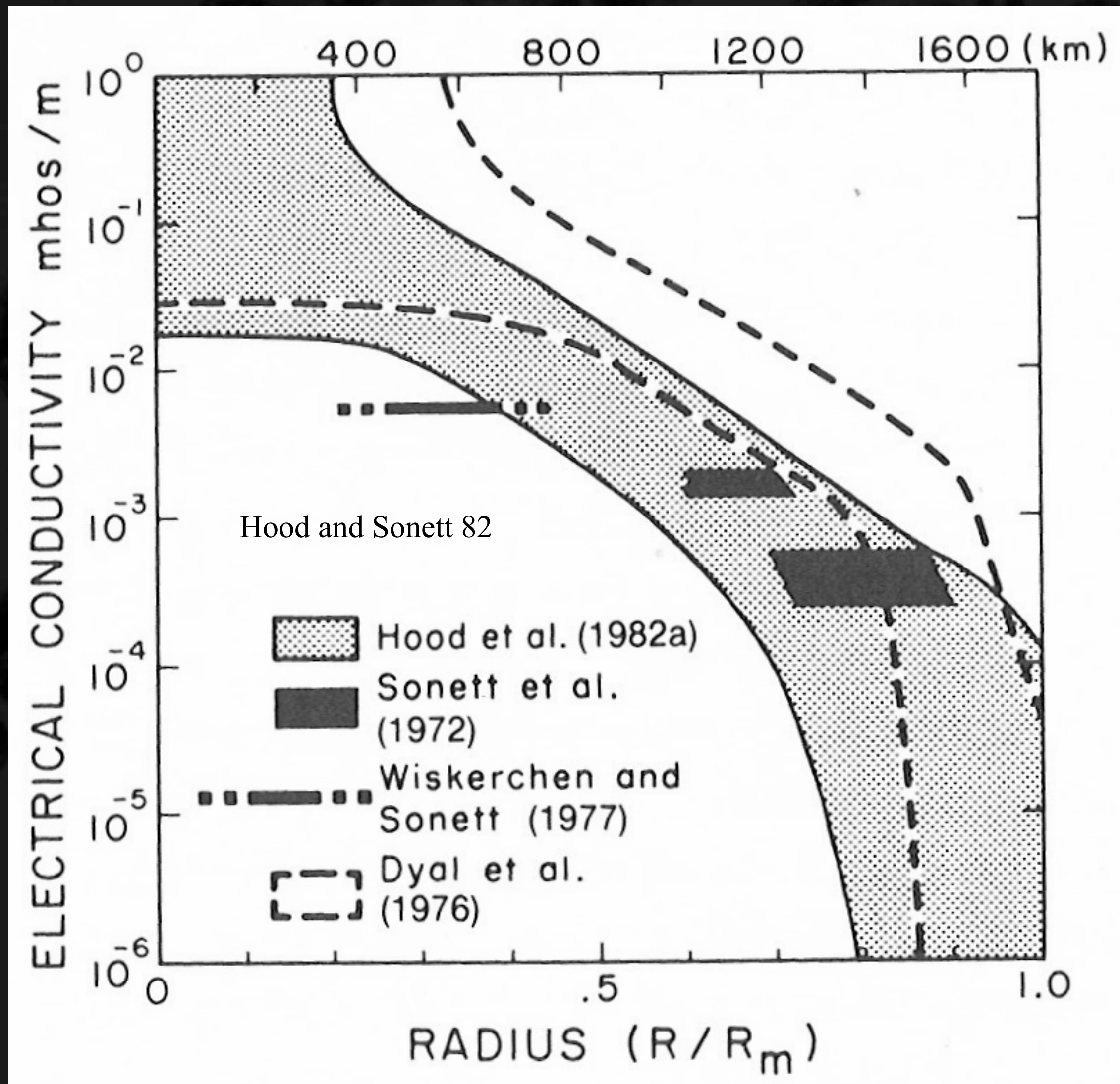
Lunar Electrical Conductivity: Experiment



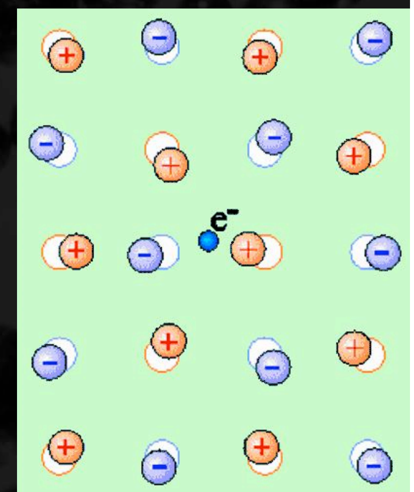
- Transfer function between distant orbiter and surface magnetometer describes global induced dipole.
- Solve for spherically symmetric layered mantle conductivity.

Lunar Electrical Conductivity: Results



Solid-State Electrical Conduction

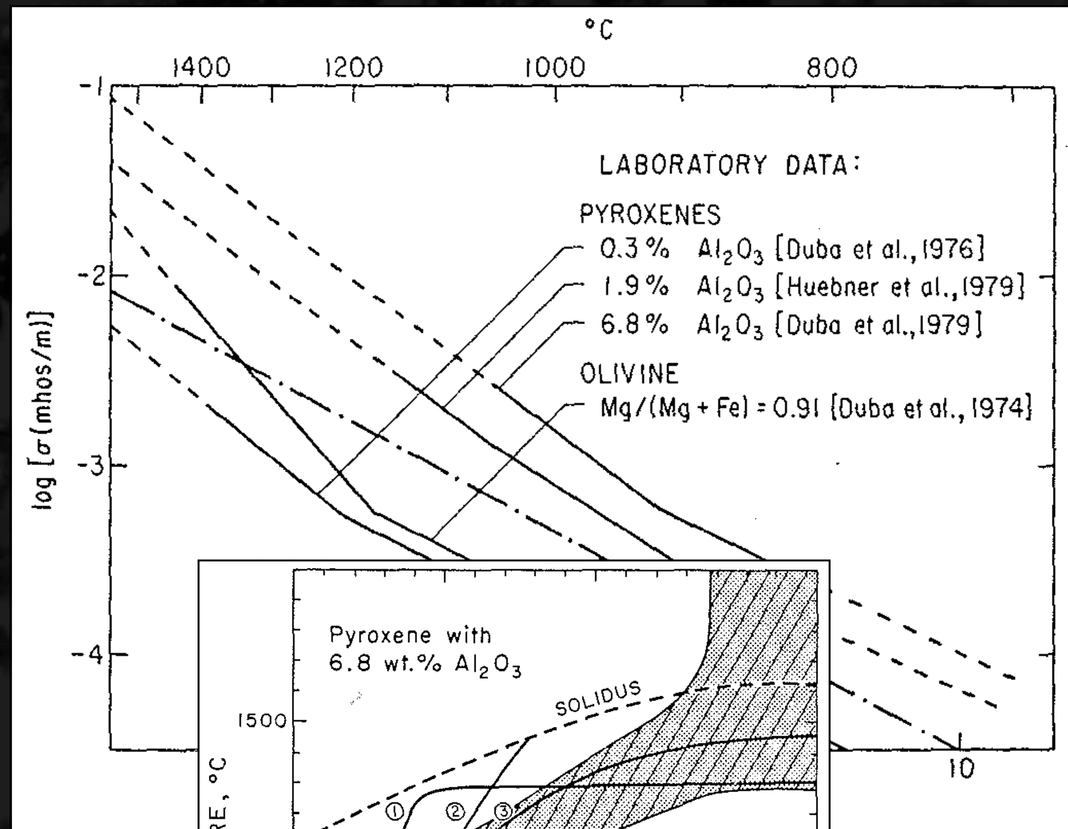
- Composition: point-defect chemistry.
  - Electron holes due to small polaron Fe_{Mg}^* extensively researched for olivine. (e.g., Hirsch and Shankland 93)
  - Trivalent-cation substitution in pyroxene tetrahedral sites (e.g., Al_{Si}') forms charge-compensating polaron. (e.g., Xu and Shankland 99).
  - Proton hopping due to hydrogen defects: H_2O dissociation. (e.g., Karato, 2006)

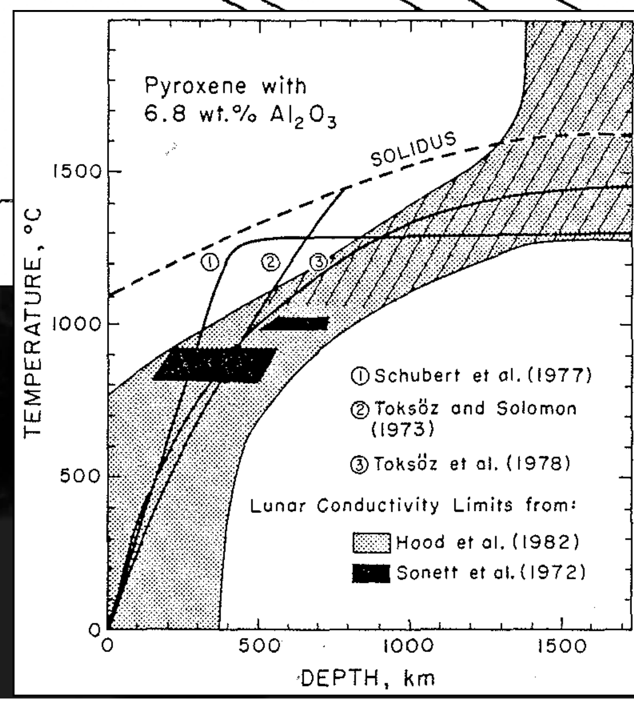


- Temperature
  - Arrhenius activation energy: $\sigma = \sigma_0 \exp(-E_a/kT)$

Effect of Al_2O_3

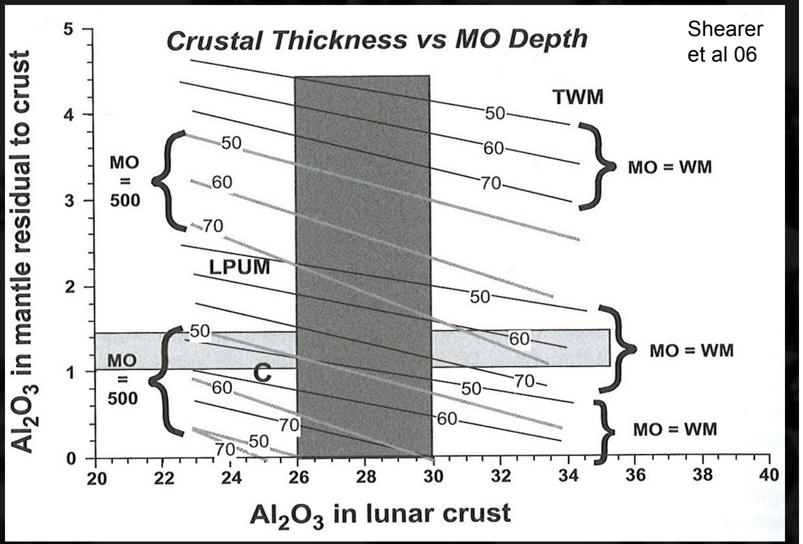
- Early modeling using (anhydrous) olivine predicted mantle temps close to melting.
- Higher conductivity of aluminous orthopyroxene allows lower temperatures. (Heubner et al., 1979; Hood and Sonett, 1982).





Al_2O_3 Abundance

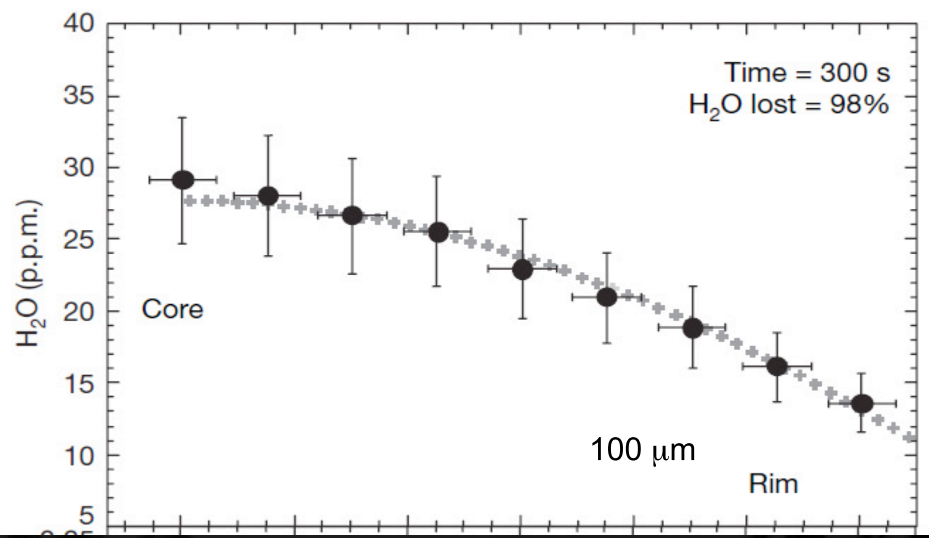
- Al_2O_3 limit in lunar mantle 3-5%.
- Pristine mantle ~50% opx, so 6.8% Al_2O_3 is 3.4% alumina in opx alone!
  - Conversely, minor plag and garnet could accommodate all inferred Al_2O_3 themselves.



- Recent modeling of lunar composition-conductivity (Khan et al., 2003) does not correctly incorporate Al substitution in opx.

Effect of H_2O

- Saal et al. (2008) used SIMS to measure 4–46 ppm H_2O in lunar volcanic glasses.
  - Modeled 745 ppm H_2O in mantle before diffusive degassing (260 ppm lower bound).

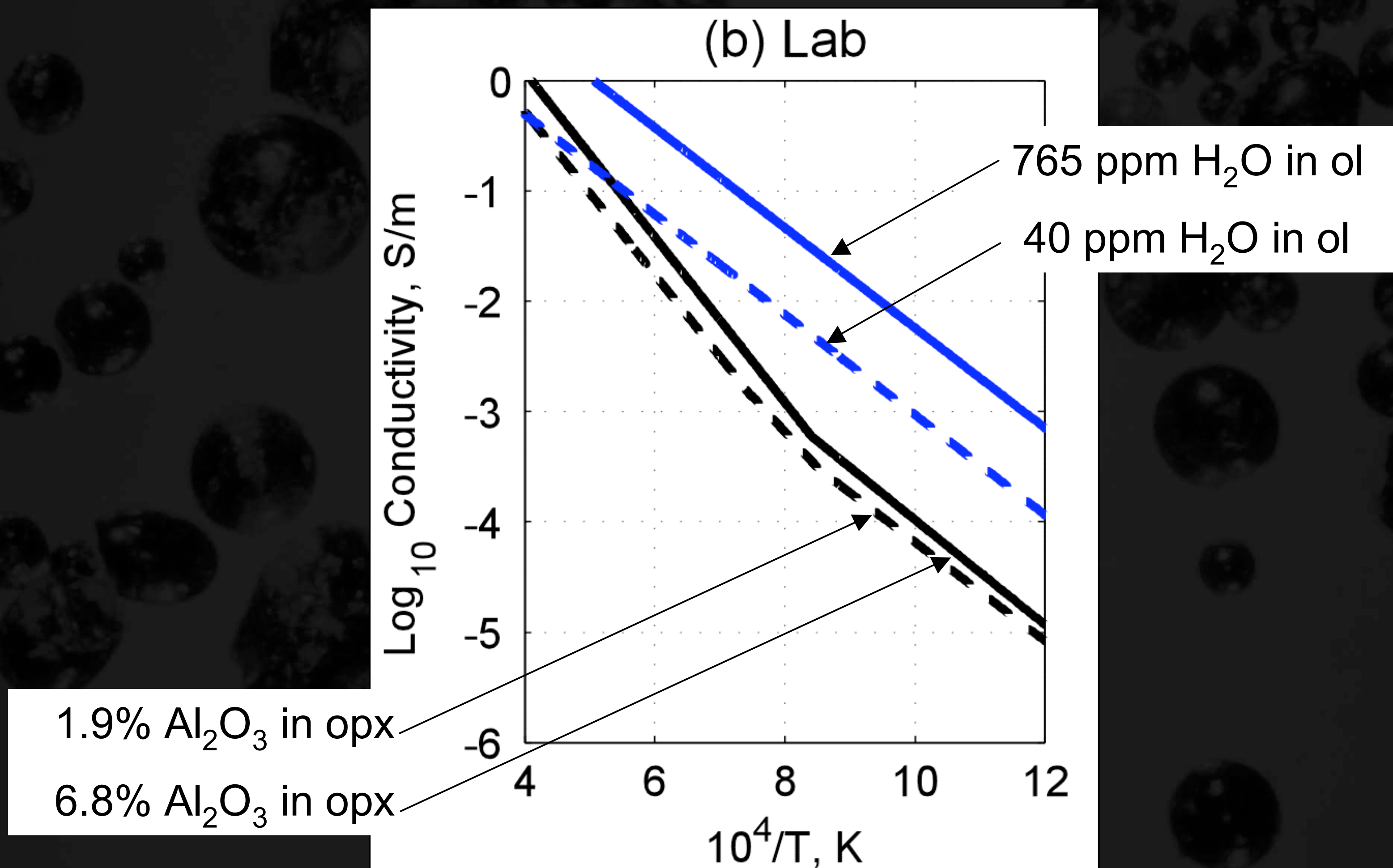


- Wang et al. 2006 measured conductivity of 10^{-2} S/m for olivine w/ 100 ppm H_2O at 1000°C.

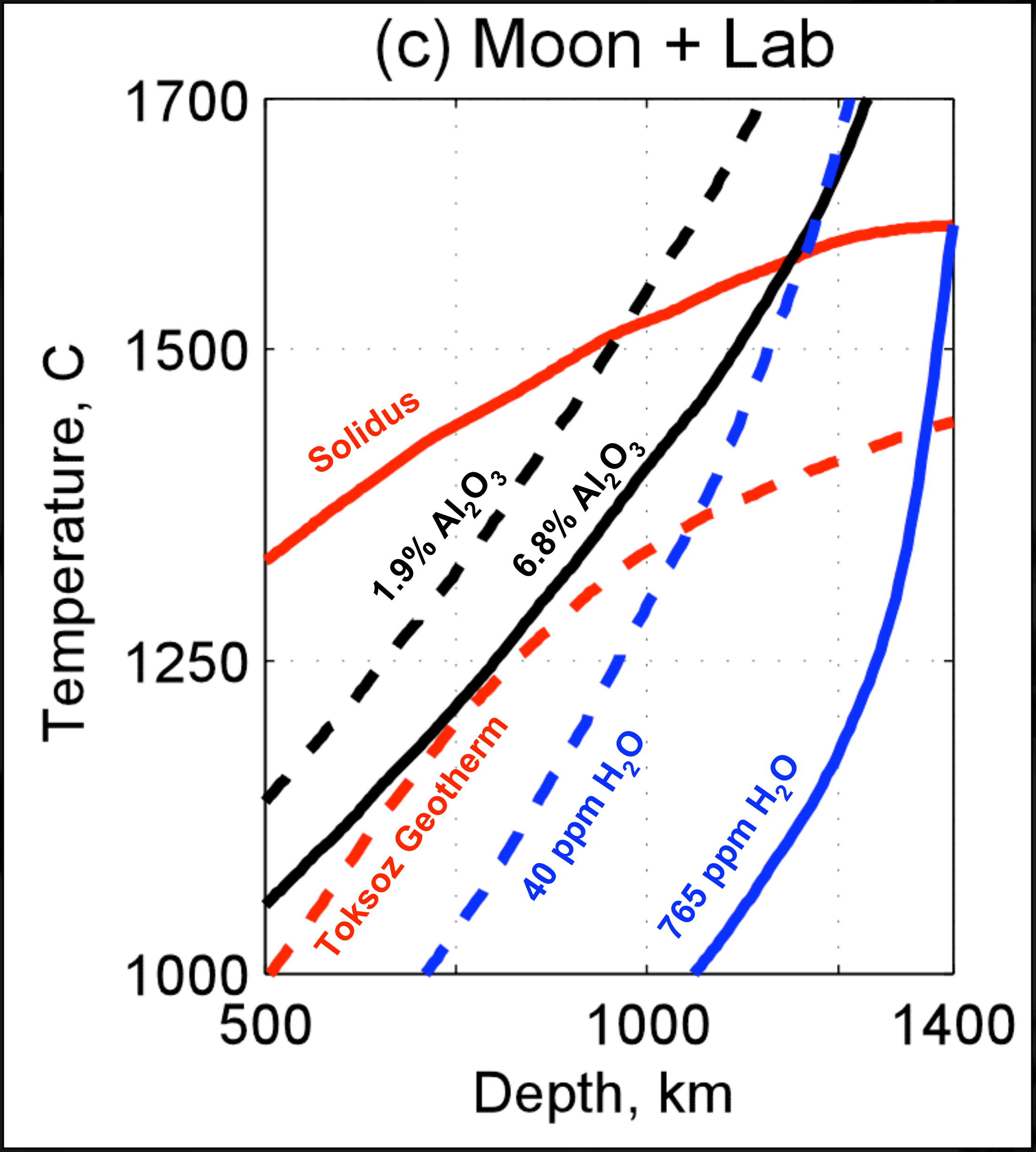
$$\sigma = 1000\ c_w^{0.67} \exp(-0.9\ \mathrm{eV} / kT)$$

c_w in wt%, exponent 0.5-0.75 predicted from mass action for 2H ionization.

Lunar Conductivity Revisited



Lunar Conductivity Revisited



- 40 ppm H_2O in ol produces same solidus crossing as 6.8% Al_2O_3 in opx.
- Order-of-magnitude lower mantle H_2O content than derived by Saal et al is acceptable.
  – Lower than terrestrial mantle.

Summary

- Early comparison of whole-moon electrical conductivity to lab measurements predicted near-melting in mantle.
- Aluminum impurities in orthopyroxene invoked to increase conductivity (lowers temps) but either too much needed or incorrectly modeled.
- Dissociated H_2O at tens of ppm is sufficient to maintain subsolidus internal temps.
- Verify with detailed composition/temperature modeling; next-generation lunar EM measurements.